Application of New Management Concepts to the Development of F/A-18 Aircraft

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The F/A-18 Program Office is large and complex. Many pressures and initiatives have compelled the office to institute new management techniques and practices. The prime contractors for the F/A-18—General Electric Aircraft Engines and McDonnell Douglas Aerospace—have also modified their practices to meet today's changing business environment. This article suggests some new ways of doing business including integrated teaming, supplier management, affordability joint process action teams, and modified maintenance concepts. It also highlights the benefits, challenges, and complexities of these applications.
(Keywords: Aircraft maintenance, F/A-18, Integrated Product Teams, Program management, Supplier management.)

INTRODUCTION

Engineers and scientists love to work with modern military aircraft like the Navy's F/A-18; the technology is advanced, the stakes are high, and the machinery is exciting. Watching a new aircraft progress through various stages of testing, production runs, and introduction into the military fleet is a thrill for those involved in the process. Even long after the aircraft design phase is complete, the challenge to maintain the aircraft's technological superiority and its combat readiness is continuous.

Today, however, another part of the story can be just as exciting. When a program reaches the size of the F/A-18 Program, it requires hundreds of people to manage it. Fiscal and political constraints overlap technical performance and often have as much influence on aircraft design as the physics that constrains technical designers. The F/A-18 Program and its prime contractors are shaping their management philosophies and techniques to meet the nation's shifting priorities and the realities of a rapidly changing business environment. Personnel at the Applied Physics Laboratory have been helping the F/A-18 Program Office (PMA-265) with a combination of technical oversight and business consultation. This article presents some new management concepts that have been applied to the development of the F/A-18.

A TEAM OF TEAMS

One example of the changes afoot is the abandonment of the matrix organizations of the past in favor of product-oriented teams (Fig. 1). Department of Defense Regulation 5000.2R of 15 March 1996 directs program managers to use Integrated Product Teams (IPTs) to the fullest extent possible. These teams are to be "composed of representatives from all appropriate functional disciplines working together to build a successful program and enable decision-makers to make the right decisions at the right time." Laboratory personnel are members of several new teams and have provided insights based on experience outside the F/A-18 Program. According to the new regulation, IPTs operate under six broad principles:

1. Open discussions with no secrets
2. Qualified, empowered team members
3. Consistent, success-oriented, proactive participation
4. Continuous "up-the-line" communications
5. Reasoned disagreement
6. Early attention to and resolution of issues

The F/A-18 Program Office recognized the benefits of IPTs before DoD actually published its requirement and has been operating with IPT concepts since mid-1992. Its program operating guide[1] describes the team structure in the F/A-18 Program Office and its fit within the larger organization at the Naval Air Systems Command (NAVAIR). NAVAIR is a competency-aligned organization that accomplishes work by integrating several competencies into IPTs, i.e., program management, contracting, logistics, engineering, test and evaluation, industrial operations, corporate operations, and shore station management.

The F/A-18 Program is complicated and encompasses the full spectrum of military procurement challenges. The Navy's structure for the program starts at the Level Zero Team, which is led by the program manager and includes representatives of the various competencies. This team incorporates an innovative approach perhaps unique to the F/A-18 Program, i.e., it includes an Executive Leadership Team whose members are senior and well experienced. As with all the teams at all levels, these top-level teams have representatives from NAVAIR, other Navy activities, and industry.

The Program Office manages the design, development, and life-cycle support of the Navy's newest carrier-based aircraft, the F/A-18 E/F; the production and systems development for previous versions of the F/A-18; and the sales of those aircraft to foreign governments. These tasks correspond to the program's three major IPTs within Level I, namely the F/A-18 E/F Engineering and Manufacturing Development Team, the Production and Systems Development Team, and the Foreign Military Sales Team.

Level II teams in the PMA-265 organization are formed around the products that concern them. For

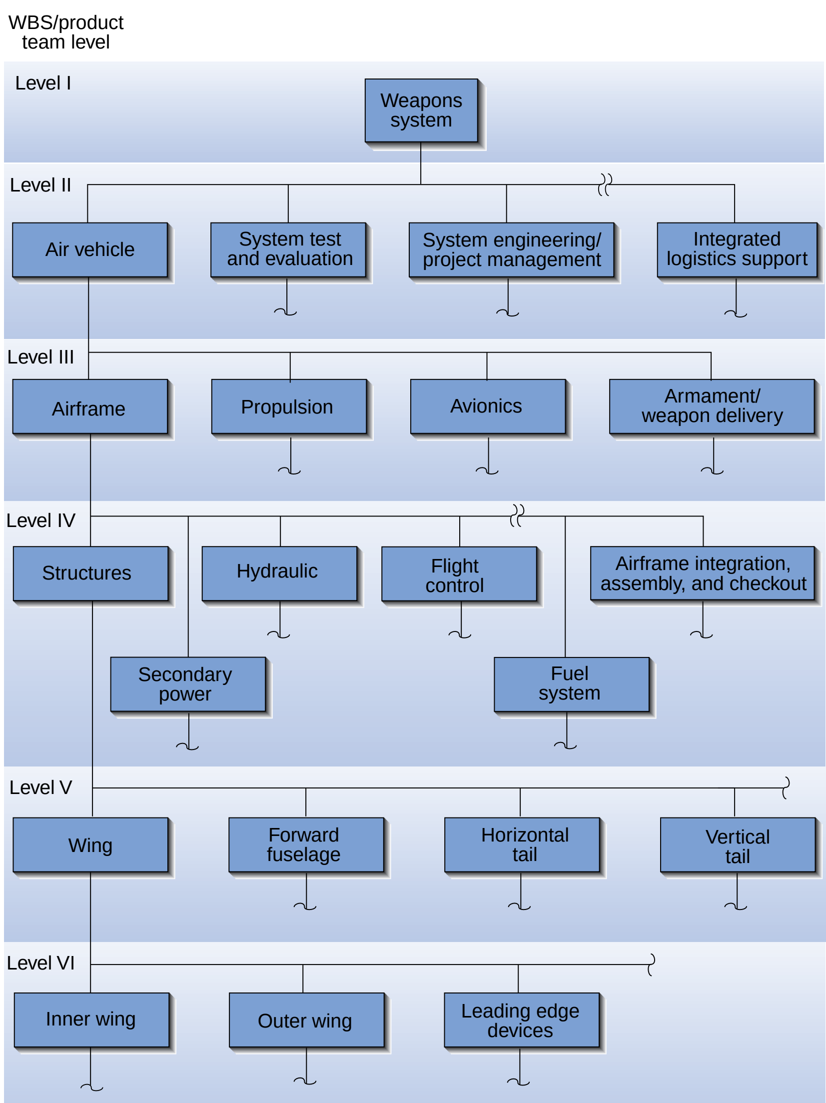

Figure 1. For the F/A-18, McDonnell Douglas Aerospace organized itself into a "Team of Teams" that interact with the Navy customer teams along work breakdown structure (WBS) lines.

example, the E/F Level I Team contains Level II teams that focus on propulsion, the air vehicle, and testing. The Foreign Military Sales Level I Team contains a team for every foreign country purchasing F/A-18 aircraft. The Production and Systems Development Level I Team contains teams for production versions of the aircraft and for each of its systems (e.g., upgraded radar) under development. Each Level II team contains Level III teams that focus on the individual products that make up the aircraft.

McDonnell Douglas Aerospace (MDA), one of the prime contractors for the F/A-18, has changed its business practices to reap the benefits of the new teaming arrangements. In a September 1991 letter to the Navy, the president of McDonnell Aircraft Company wrote: "Traditional management techniques and the old ways of doing business will not suffice. . . . We have committed our F/A-18 E/F program to full implementation of Integrated Product Development/Concurrent Engineering practices."

For the E/F engineering and manufacturing development program, MDA has formed teams along product lines that mesh with the Navy's teams (with the exception of the Level Zero Team). The MDA structure (Fig. 1) has six levels, with the lower levels working on individual components and subassemblies. An important characteristic of these teams is that they include Navy personnel. The Level IV and V teams that concern themselves with landing gear, for example, have Navy members who are technically responsible for landing gear development. Navy personnel representing other competencies might also serve as team members; e.g., Navy engineers responsible for material strength, hydraulic reliability, production, and landing gear maintenance will be on the same team as their counterparts at MDA.

When the team is focused on a component such as landing gear for which there is a major subcontractor, that subcontractor will have its own representatives on the team. The teams meet regularly for system development, production, and support. Concurrent engineering is easier since all stakeholders are team participants from the beginning.

Consider, for example, the E/F team's development of the new crew station display,[2] a multipurpose color display using a 6 × 6 in. active matrix (Fig. 2). Within its electronic architecture are the processors to drive the display for video, radar imaging, and graphics. It also provides much of the processor power for the up-front control display unit, which is to be developed by the same supplier. This small unit must conform to an existing space in the aircraft's head-up display. It uses modern application-specific integrated circuits with gate counts in the hundreds of thousands. To meet difficult packaging requirements, most of the circuitry uses double-sided surface-mount technology. Ada is the specified software language.

The technology for the display is very interesting, but MDA's teaming approach to its development is equally interesting. To begin, MDA worked with the Navy as a team to develop a general idea of what the display should be. Then they sent a request for information to six potential suppliers. Of the six, two convinced MDA they could continue the development. With each of the two potential suppliers, MDA formed integrated product development teams that actually developed the package of requirements and specifications that MDA would later use for the development effort and subsequent production.

Using the suppliers on the teams to develop the procurement package proved beneficial to the Navy, MDA, and the suppliers. It eliminated ambiguities early in the development process and minimized design iterations and production rework.

Figure 2. An early rendition of the crew station display for the new F/A-18 E/F. The multipurpose color display is prominent in the center of the picture.

Integrating the suppliers into IPT teams was not without challenges, however. For one thing, the MDA and Navy team members were on both teams with the separate suppliers. It was difficult to prevent disclosing to one supplier the proprietary information of the other. Also, meetings with the two teams were expensive since they required people in many different disciplines to travel and spend days in the requirements development process.

According to MDA, the extra effort and expense paid off. All team members knew and bought into the systems requirements before the contract was awarded. When MDA finally awarded a contract to Kaiser Electronics, everyone was ready to continue the development effort. There was no need to educate the new subcontractor about system requirements. The same team that began the process continued through the various stages of preliminary and detail design and finally into production. They met once a month. Technical experts from the Navy were on hand throughout as team participants to ensure that the crew station display met the aircraft's needs.

MDA and the Navy used integrated product development teams to develop and produce all the new systems for the E/F aircraft. Another dramatic example of the advantages of integrated product development was the approach taken by General Electric Aircraft Engines (GEAE) to the development of the F-414 engine. This prime contractor formed teams with select suppliers and with the Navy to ensure that the new engines were developed and produced within budgetary and time constraints (only 42 months between project start and first engine test).

One significant part of the GEAE approach was abandoning the traditional belief that an entire design needed to be finished before a supplier could be involved to produce parts. Instead, GEAE called key suppliers in as early members of the team and began working with them in component design. The suppliers and GEAE began producing parts as soon as possible using whatever definition was available. For example, instead of GEAE producing a complete and approved design for a blisk (combined blades and disk) forging before providing it to the forging house, they ordered the new part based on a written description of changes they would need to a previous design. In this way, the forging house could offer design suggestions that would ease production and even enhance performance. Figure 3 illustrates the development time GEAE saved by using the concurrent engineering approach.

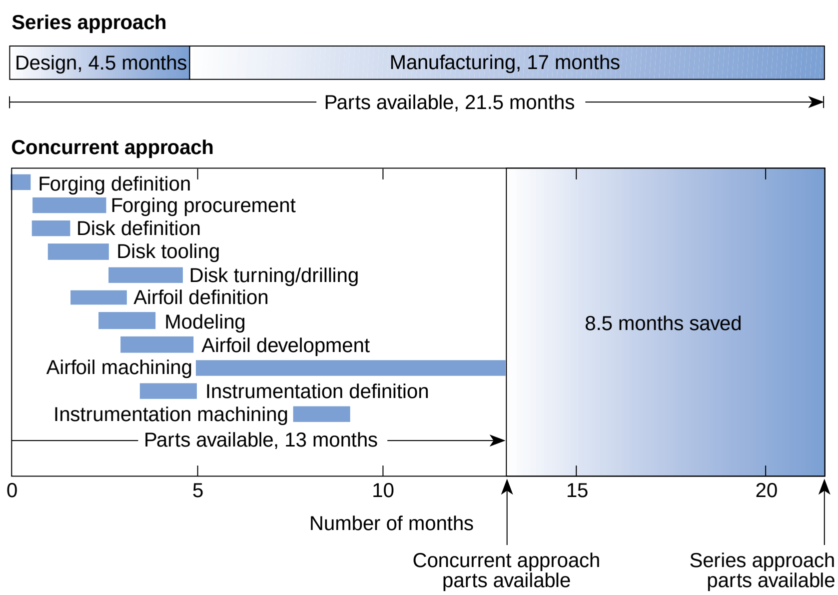

Figure 3. New techniques in concurrent engineering and supplier teaming saved General Electric Aircraft Engines months in component development time. This example contrasts development time for a blisk (combined blades and disk) forging by the series approach and the concurrent approach.

SUPPLIER MANAGEMENT

According to Bhote,[3] only 5% of the cost of modern equipment is attributable to direct labor, yet 50% of a company's attention goes to managing direct labor. A greater percentage of equipment cost goes to outside suppliers, but until recently, many manufacturers assumed that suppliers could manage themselves. It was the manufacturer's responsibility to tell the supplier what was needed and the supplier's responsibility to provide it.

For the F/A-18, 74% of the aircraft production cost (excluding engines) goes to MDA's suppliers. More than 2700 companies in 47 states furnish the 70,000 parts that comprise an F/A-18 E/F aircraft. In California, a state with a large aircraft industry base, F/A-18 E/F production will account for 11,500 jobs in 805 companies producing annual revenues of $1.3 billion.

Not all of these companies sell directly to MDA and GEAE, the prime contractors. Many are in the third or fourth tier of the supply structure, and at each tier, the prime contractors have less managerial insight and control. That doesn't make lower-tier suppliers any less important. In the past, suppliers at all levels might have been the source of major problems. Even the simplest parts can hold up a production line if the supplier cannot deliver on time. For lack of raw material from a mining company, a specialty steel mill can slow down a forging house, which slows down a machine shop, which fails to provide a finished part to an assembly shop, which fails to deliver a component on time for aircraft production. Poor quality at suppliers' plants leads to problems in assembly. Incoming inspections, intended to catch quality problems, are time-consuming and can cause production delays.

With help from APL, the F/A-18 Program Office has established a new organization, the Supplier Management Team, to work with the prime contractors to improve their supplier management techniques. By direct interaction with technical teams that include major suppliers, the Supplier Management Team has a good understanding of the prime contractor–supplier interface and can therefore often prevent most of the supplier problems that have plagued military procurements in the past.

Military aircraft manufacturers, like most large equipment manufacturers, are becoming more dependent on their suppliers. Matters have become too complex for any one company, even a large company, to possess all the necessary expertise. Computer programs that make solid models and do finite-element analysis are extensive; it takes training to operate them. Many large companies have found it cost-effective to hire specialized design firms to do their structural engineering and design tasks. These firms own the expensive computer software and have the expertise to do structural engineering. However, someone must be able to tell the structural engineering firms about the functions of the part and what kinds of loads the part will see in service. Some sort of partnership must exist between the prime contractor who knows what the part must be and the subcontractor who knows how to design it.

New electronic equipment is also more complex. A constant pressure to reduce the size and weight of electronics, especially for aircraft, is clearly evident. One way to achieve this reduction is to use customized integrated circuits, such as the application-specific integrated circuits Kaiser used in its display circuitry. At any rate, the process of designing circuitry and translating circuit descriptions into specific silicon and metal shapes is complicated. Smaller companies specialize in the new processes because large companies cannot afford to keep the specialized talents for those infrequent occasions when they might be needed. Often, the most experienced custom circuit designers work on a freelance basis or align themselves with contract administrating companies, a setup that adds to supplier management complications.

Companies like MDA that are under contract to develop large, modern systems must become closely aligned with their suppliers. The technical details are immense. It is impossible for the systems designer and integrator to simply write a purchase order and expect the supplier to know exactly what he wants. Throughout the design process, the customer, the systems integrator, and the suppliers must interact constantly to meet their common goal.

Now that prime contractors have begun to focus more of their management attention on suppliers, they are finding that managing suppliers is as difficult as managing people. Like their own employees, supplier companies have individual personalities. Greiner[4] notes that the differences can be attributed to the age and size of the company. He describes five stages of organizational growth (Fig. 4). After each stage, a company must go through a period of revolution to reach the next stage. After Stage 1, growth through creativity, for instance, a new company begins to find that the free-wheeling entrepreneur who founded the company probably lacks the leadership necessary to direct its future development. A leadership revolution brings the company to the next growth stage, and so on through the stages.

Table 1 shows the characteristics of companies during their growth stages. MDA and GEAE have the characteristics of Stage 5 as do many of their suppliers, and even many of the subtier suppliers. Most suppliers are in Stages 1 through 4, however, and the prime contractors must manage them all. Not only do the various companies have different characteristics depending on stage, but they continually change stage. Each stage requires a different management approach

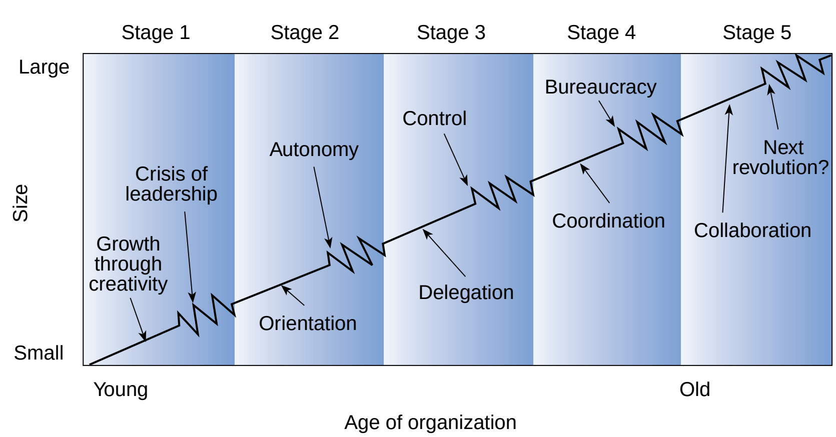

Figure 4. Supplier companies go through various stages of growth. Between each growth stage a revolution must occur.

Table 1. Organization practices during evolution.

Organizational characteristics	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Management focus	Produce and sell	Efficiency of operations	Expansion of market	Consolidation	Problem solving/ innovation
Structure	Lax	Centralized/ functional	Decentralized/ geographical	Line staff/ product groups	Matrix of teams
Top managment style	Individual entrepreneurial	Directive	Delegative	Oversight	Participative
Control emphasis	Market results	Standards/ cost centers	Reports/ profit centers	Plans and investment centers	Collective goal setting
Reward system	Ownership	Salary/merit increases	Individual bonuses	Profit-sharing stock	Team bonuses

from the prime contractor, which means that the management approach must continually change as well.

According to Bhote,[3] prime contractors can make important improvements by reducing the number of suppliers. Reducing the supplier base is a prerequisite to attaining all the advantages and benefits of a customer–supplier partnership. The F/A-18 prime contractors must have agreed; GEAE has reduced the number of its production suppliers by a little over 50% from 1987 to 1994, and MDA has made similar reductions.

Partnerships with suppliers, concurrent engineering, and supplier membership on IPTs should lead to a spirit of trust between prime contractor and supplier. However, even with the trust between parties, a need to verify performance may still exist. For that reason, both GEAE and MDA have supplier performance monitoring programs.

GEAE uses six criteria in what they call their Supplier Excellence II Program. The criteria are weighted by percentage to emphasize their importance to the company, i.e., quality, 30%; technology, 20%; speed, 20%; productivity, 15%; leadership, 10%; and finance, 5%. GEAE's best suppliers maintain scores close to 100%, and to be considered satisfactory they must maintain a score of at least 80%. Satisfactory suppliers are given more latitude to manage themselves. Suppliers with scores below 60% are unsatisfactory, and GEAE provides more oversight and direction for them. If they do not improve, GEAE will phase them out and remove them from the supplier base.

Note that GEAE puts as much emphasis on speed as it does on technology. Improving speed and productivity has been a characteristic of the General Electric Corporation since Jack Welch became its chief executive officer.[5] For its suppliers, that means continuously reducing cycle times by improving administration, engineering, and production.

GEAE uses a technique called "action workout" to improve processes. The company appoints a facilitator trained in this technique to interact with two teams—the Leadership Team, which is composed of people who can make decisions to get processes changed, and the Participants Team, which is composed of those who are most involved in the process.

The Participants Team examines the entire process to identify unproductive time and unnecessary steps. Once the process is understood and its defects exposed, this team indicates changes to improve the process. Full consensus of the team members means that they are ready to take the recommendations to the Leadership Team. The Leadership Team, in turn, accepts (or rejects) the recommendations and then assigns action items to implement the recommendations it accepts.

The advantage of the action workout process is that it occurs during a finite period of time, usually less than 90 days. One rule is that the Participant Team cannot delay the process by, for example, recommending another analysis team. Both action workout teams meet during regular working hours; their activities are considered as important as their permanent jobs. The process has enabled GEAE to increase productivity. At National Broadcasting Corporation, a GE division, one department used this system to eliminate forms that used over 2 million pieces of paper per year. MDA and its major F/A-18 subcontractor, Northrop Grumann, have both used the workout system to improve their processes as well.

MDA uses a rating process called SPEARS (Supplier Performance Evaluation and Rating System) to establish baselines and measure performance in terms of quality, delivery, and responsiveness. These ratings are used in conjunction with other management indicators, such as cost of quality, cost of delivery, cost of doing business, and process improvements. Using SPEARS, MDA assigns three levels of certification to its suppliers. Table 2 summarizes the standards for certification and preferred status.

MDA keeps track of its suppliers using a metric system that includes many of the SPEARS reporting functions. Trained supplier managers are assigned to IPTs and select those characteristics that best apply to the particular supplier. They are aided in this decision by a “shopping list” like the one shown in Table 3. Criteria can be added if necessary to tailor performance monitoring to a specific supplier.

Once the list is established, the supplier manager summarizes the results in color charts that show at a glance which suppliers need immediate attention (red), which require a watchful eye (yellow), and which are doing well (green). Table 4 shows the chart as it is presented to upper management at MDA and the Navy.

AFFORDABILITY JOINT PROCESS ACTION TEAMS

The reduction in DoD acquisition budgets has forced the Navy to emphasize reducing the flyaway costs of its new aircraft. MDA’s sales to foreign nations depend on the price of an F/A-18 being competitive with that of other military aircraft worldwide.

Perhaps the greatest advantage to the team approach and supplier management has been the openness with which the Navy and MDA can solicit ideas from suppliers. To help reduce the cost of F/A-18 aircraft, MDA and the Navy have formed Joint Process Action Teams with their suppliers. During a typical team meeting, suppliers make money-saving suggestions to MDA and the Navy. For example, in 1985, W. J. Willoughby, Jr., then the chairman of the Defense Science Board Task Force on Transition from Development to Production, published the so-called

Table 2. Three levels used by McDonnell Douglas Aerospace to certify suppliers.

	Assessment of processes		Performance			
			Quality		Delivery	
Certification level	Total business assessment	Statistical process control (SPC) requirements	Acceptance (%)	Period (months)	On-time percentage	Period (months)
Gold	(4.5–5.0) (min. 4.0)	12 months of acceptable SPC performance	99–100	12	99–100	12
Silver	3.5–4.4 (min. 3.0)	6 months of acceptable SPC performance	98–99	12	95–99	6
Bronze	2.5–3.4 (min. 2.0)	Documented plan and implementation schedule of SPC	95–98	12	90–95	6

Table 3. Sample of performance criteria used by supplier managers.

Cost	Schedule	Quality	Technical performance	Cycle time	Inventory
Equivalent earned value	Delivery	Production yield	Weight	Build cycle	Work in progress
Affordability initiatives	Performance to plan	Subtier yield	Reliability	Process flow	Shortages
Allocated budget	Subtier delivery	Subtier quality	Maintainability	Rework cycle	Tooling
Design to cost	Critical path	Documentation	Key specifications	Response cycle	Inventory management system
Cost performance index	Data submittals	SPEARS quality	Test status		
	SPEARS[a] delivery	Defects per unit			
	Schedule performance index	Current quality			

[a]SPEARS = Supplier Performance Evaluation and Rating System.

Table 4. Supplier performance summary.

Supplier	Equipment	Feb	Mar	Apr	May	Jun	Jul	Aug
A	Electronic warfare antennas	Red	Red	Red	Red	Red	Red	Red
B	Multipurpose color display	Red	Red	Yellow	Yellow	Yellow	Red	Red
C	Engine fuel display	Yellow	Yellow	Red	Red	Red	Red	Red
D	Pitot static/total temperature monitor	Green	Green	Green	Yellow	Yellow	Red	Red
E	UHF/VHF/L-band antenna	Green	Green	Green	Green	Green	Red	Red
F	Air data sensor unit	Green	Green	Green	Green	Yellow	Red	Red
G	Flight test hardware	Green	Green	Red	Red	Yellow	Yellow	Yellow
H	Pressure transmitter set	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
I	Stores management set	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
J	Aft electronic warfare antenna	Green	Green	Green	Green	Green	Green	Green
K	Global Positioning System	Green	Green	Green	Green	Green	Green	Green
L	Signal data computer	Green	Green	Green	Green	Green	Green	Green
M	Up-front control display	Red	Red	Yellow	Yellow	Yellow	Green	Green
N	Flight controls	Yellow	Yellow	Green	Green	Green	Green	Green
O	RF cables	Green	Green	Green	Green	Green	Green	Green

Note: Green = performing to plan, yellow = attention required, red = action required.

Willoughby templates.[6] In one template he recommended that equipment vendors rescreen (retest) 100% of the electronics parts received from manufacturers. This would reduce expensive troubleshooting and rework at higher levels of assembly. The rescreening template claimed the cost to retest was about $1, compared with $1500 to repair fully assembled equipment.

Willoughby asserted that some electronic components such as semiconductors showed defect rates of 3% to 12% during user rescreening.[6] Recent F/A-18 experience differs dramatically. Major avionics suppliers reported that greater than 99.99% of parts tested successfully. A comparison of hermetic and nonhermetic electronic components showed that both failure rates improved on average from 0.5 to 0.02 failures per million operating hours.[7]

The reduction in defect rate reflects an overall increased emphasis on quality and statistical process control. Market forces have eliminated all but the best component suppliers, and prime contractor supplier certification programs ensure best-in-class suppliers. By eliminating the rescreening requirement with help from APL, the Navy is saving $75,000 for each aircraft it purchases.

Suppliers also recommended using commercial or industrial electronic components because components manufactured to military specifications are more expensive. Modern commercial electronics are available in a wider variety of configurations, and commercial equipment can be one-fourth the size of equipment manufactured with military electronic components. The question, of course, for military engineers is whether the commercial components can be as reliable. The F/A-18 Program Office formed a team that included APL to answer those kinds of questions. The results of some of that team's work are presented in the article by Casasnovas and White elsewhere in this issue.

MODIFIED MAINTENANCE CONCEPTS

Many suppliers to the F/A-18 claim they can reduce their price by 5% to 10% if the Navy allows them to have configuration control of their equipment and do all but the simplest maintenance. In addition, they argue that the Navy would benefit from savings in life-cycle costs (e.g., maintenance training, test equipment, documentation).

The military services currently use three levels of maintenance: organic, intermediate, and depot. Organic maintenance is limited to removing subsystems from aircraft for repair. Intermediate-level maintenance incorporates sufficient test equipment and personnel to make many repairs at lower assembly levels. The depot is equipped to make complete repairs.

The Navy is considering reducing intermediate-level maintenance to save money. They are also considering reducing the workload at their own depot facilities like the Naval Aviation Depots and sending items that need repair to the original equipment manufacturers (OEMs). These manufacturers could make equipment changes more efficiently to improve performance, overcome obsolete technology problems, and reduce production costs. On the other hand, the Navy must ensure that changes in maintenance philosophy do not degrade overall aircraft readiness. Decisions about maintenance philosophy are complex. They involve technical and logistical issues as well as cost trade-offs. The F/A-18 Program Office established the Modified Maintenance Team, with APL membership, to sort it all out. Figure 5 is a flow chart to help managers make decisions about modified maintenance concepts. This chart and the thoughts behind it were the subject of much of the Modified Maintenance Team's activities. It illustrates the complexity of maintenance decisions.

Managers must consider system maintenance philosophies on three levels—the system level, such as the radar; the weapon replaceable assembly (WRA) level, such as the radar receiver; and the shop repairable assembly (SRA) level, such as an individual circuit card within the radar receiver. Decisions about maintenance differ for legacy (already in production) equipment and new or developmental equipment. An approved maintenance decision process called Level of Repair Analysis (LORA) is available for new equipment. Military Standard 1390D describes LORA. Its output is a decision about the most cost-effective use of military maintenance activities. It decides whether to use organic-, intermediate-, and/or depot-level maintenance and does not consider using the OEM as the intermediate- or depot-level maintenance activity.

The team uses the LORA as a starting point for life-cycle cost analysis about new systems, then continues the analysis with non-LORA factors such as non–cost related aspects of safety; military security; support and test equipment; packaging, handling, storage, and transportation; facilities; configuration control and item management; technical proficiency of maintenance personnel; obsolescence; and risk. The team then modifies its analysis to include any cost-related aspects of these factors.

The leg of the flow chart for legacy systems begins with "obsolete parts problem." Any SRAs with "systemic" obsolete parts problems would be good candidates for (OEM) depot maintenance. This allows the OEM to change the SRA, eliminating obsolete parts, without going through a lengthy configuration management process. When the Navy performs maintenance, the OEM must ensure that changes to SRAs coincide with changes to maintenance documentation and spare parts inventories.

For those systems that do not have obsolete parts problems, MDA uses an analysis tool called the Supportability Assurance Readiness Program, which looks at equipment history records to produce statistics such as the percentage of time that repair was beyond the capability of the maintainer (BCM), the mean time between removals (MTBR) of equipment from the aircraft, and the percentage of time a depot received the equipment for repair but could not duplicate (CND) the problem.

Occasionally, the analysis will uncover a problem that can be easily fixed by changing integrated logistics support. If, for example, the CND rate for a particular piece of equipment is much worse at one maintenance site than at another, the problem might be training, support equipment, documentation, or parts availability at that particular site. In such cases, decision makers would implement the easy solution before attempting additional analysis.

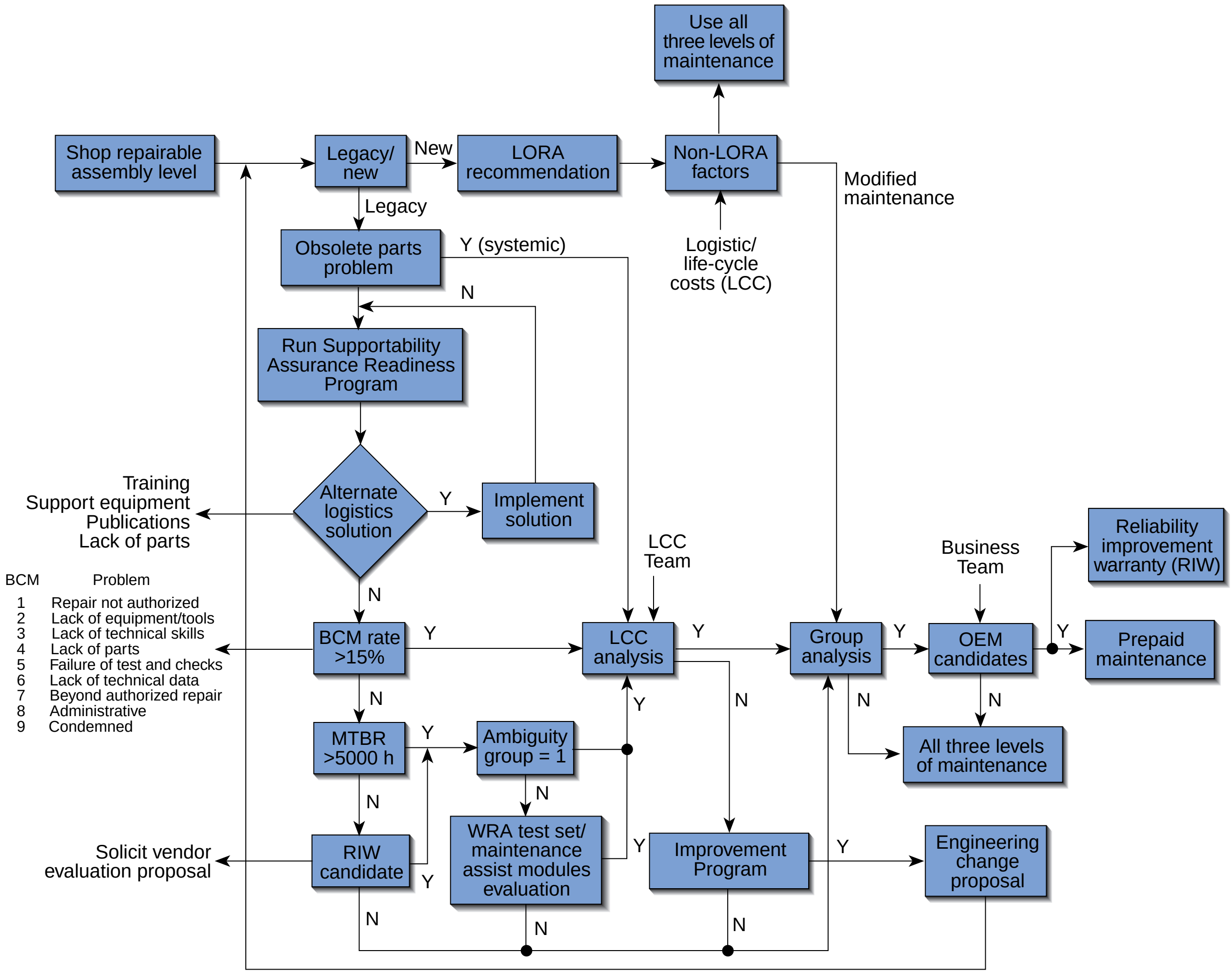

Figure 5. Decisions about maintenance are complex and involve technical and logistical issues as well as cost trade-offs. (LORA = level of repair analysis, BCM = beyond the capability of the maintainer, OEM = original equipment manufacturer, MTBR = mean time between removals, WRA = weapon replaceable assembly.)

The Modified Maintenance Team uses these statistics as filters for deciding which equipment to further analyze. For example, equipment that has often been beyond a maintainer's repair capability would be a good candidate for a move to OEM maintenance. The team used Pareto analysis to establish a threshold for the BCM rate (Fig. 6).

Unfortunately, no similarly strong Pareto effect exists for MTBR; only a gradual change in the number of SRAs affected is seen as the MTBR rate changes. Because the team lacked a better selection method, it used a rate of 5000 h. This allowed about half the SRAs to remain in the process for further analysis. As the team gains experience with this method, the initial set point will be adjusted.

Any equipment with reliability below the 5000-h threshold might still be good for OEM maintenance if the manufacturer commits to improving the reliability to the threshold. The team suggested that before equipment is rejected for further analysis, the Navy should formally request the vendors' commitment to a reliability improvement warranty or something similar. Normally the Navy would expect the OEM to make such improvements within 5 years.

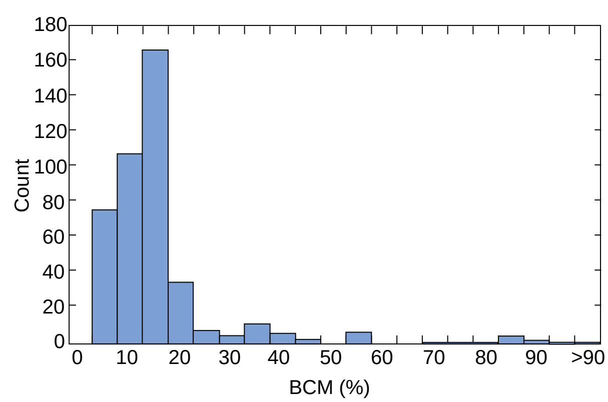

Figure 6. Pareto analysis showed most equipment has a beyond the capability of the maintainer (BCM) rate of less than 15%. By setting a threshold there, the Modified Maintenance Team selects for original equipment manufacturers depot maintenance equipment most difficult to repair.

As mentioned previously, an important consideration in OEM maintenance decisions is the percentage of times an SRA is removed for repair and the repair facility cannot find anything wrong with it, i.e., the CND, which is derived from equipment history records. Unfortunately, a percentage rate is not a good metric for CND because increasing reliability decreases the number of times removed and increases the CND percentage—a false indication that something is wrong. The Modified Maintenance Team, however, found a better indication of false-alarm rate.

Aircraft built-in test circuits inform maintenance personnel when a problem exists with a certain WRA. As configured in the F/A-18, such a test does not isolate a failure to a particular SRA. Instead, the maintenance shop uses special test equipment to show the specific location of a fault. Often, this equipment can indicate only that the fault is within a group of SRAs called an ambiguity group. Maintenance personnel try to reduce the size of the ambiguity group by substituting SRAs within the group with SRAs known to be fault-free.

In some cases, the shop has access to specially provided SRAs called maintenance assist modules. These "golden SRAs" are kept in reserve for fault finding by substitution only. They are not to be used as replacements for faulty SRAs. (Sometimes, however, the shop might use a maintenance assist module as a replacement if it is the only means available to get an aircraft back in service.)

A piece of equipment for which the shop cannot isolate faults to a single SRA is not a good candidate for the OEM to assume depot- and intermediate-level maintenance. If, for example, the shop can isolate a fault to an ambiguity group of three, then all three SRAs in the group are suspect. With the OEM performing the maintenance, the three SRAs would enter a logistics pipeline that includes transportation, administration, and OEM repair. To keep aircraft flying, the maintenance shop would need three spare SRAs instead of one to cover the potential absence of the three SRAs during the repair turnaround. The extra expense of the spare SRAs probably negates any savings OEM maintenance might provide. However, the size of an ambiguity group may be reduced by improving the test program sets within special test equipment or by providing more maintenance assist modules.

The Modified Maintenance Team recommended a life-cycle cost analysis for any equipment that other filters do not eliminate from further OEM maintenance considerations. If the analysis shows that a piece of equipment is not a good candidate for OEM maintenance because of costs, it might be possible to improve its chances with a preplanned product improvement program that would result in an engineering change proposal to the equipment. At that point, the equipment would be reanalyzed. If preplanned product improvement is not possible, the equipment should continue to use all levels of the maintenance program.

If all these analyses finally show that the OEM should maintain an individual SRA, what happens to the other SRAs within the WRA? Would the OEM give a better price if it maintained all the SRAs it makes for the F/A-18? Would it be easier for a given OEM to make configuration changes to one SRA if it could also change the other SRAs within the WRA? These kinds of questions would be answered with what the team calls a group analysis.

The last part of the decision process would be the type of maintenance contract to enter with the OEM. One type already mentioned is the reliability improvement warranty, a contract requiring the OEM to provide additional spare SRAs into the logistics pipeline if it cannot improve reliability by a specified, predetermined amount each year during the contract. The intent is to make it cheaper for the OEM to improve reliability on its own than to endure the costs of producing extra spares.

A prepaid maintenance contract pays the OEM up front for equipment maintenance during the contract period. The contract is for a fixed price based on the equipment's predicted field reliability. Of course, if the OEM can improve equipment reliability by configuration changes or better maintenance, it can lower its costs and improves its profits. Renegotiation for follow-on contracts would adjust the contract amount to the new reliability.

All in all, decisions about equipment maintenance might be the most complicated the F/A-18 Program Office makes. Such decisions involve not only the aircraft's advanced technology, but almost every aspect of its life cycle.

CONCLUSION

By almost any measure, the F/A-18 is a successful military acquisition program. The combat-tested F/A-18 aircraft are among the world's best. The upgraded E/F version recently finished the engineering and manufacturing development phase of its acquisition cycle. The first flight was 1 month early with no cost overruns, and the aircraft weight was 1000 lb below the specification. The aircraft's technology is complex and challenging, but just as challenging is managing the thousands of people and the hundreds of organizations that contribute to its success.

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